Visualization of Earthquake Simulation Data

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Outline

- Introduction & Background
- Visualizing simulated surface displacements using RIVA
- Visualizing 3D tensor data using ParVox
- Visualizing stress and slips on the fault segments using MSLT
- Integrating visualization tools into the QuakeSim portal
- Status & Conclusion

Introduction & Background

- Apply two parallel visualization systems (ParVox and RIVA) developed under the ESTO/CT program to visualize the time-varying, 3D earthquake simulation datasets.
- Develop Multi-Surface Light Table (MSLT) to visualize fault segments and their dynamic characteristics.
- Support the visualization needs for the QuakeSim team.
  - Visualize the simulation data from two major QuakeSim models: GeoFEST and Virtual California
  - Integrate the visualization systems into the QuakeSim portal to support remote users.

The Earthquake Simulations

- GeoFEST (Parker, Lyzenga, JPL)
  - A 3D finite element model that models the stress and flow in the Earth's crust and upper mantle in a complex region such as LA basin.
  - It produces stress and strain due to the elastic response to an earthquake event.
  - 3D unstructured dataset with stress tensors on the elements and displacement vectors on the nodes
  - Will soon generate unstructured AMR data set
- Virtual California (Rundle, UC Davis)
  - A Monte Carlo method that generates simulated, realistic earthquakes on an arbitrary surface mesh.
  - Simulation of the fault systems spanning the region of California
  - It produces stresses and strike-slips on the fault segments. The slips on the fault segments can be interpolated to produce surface displacement.

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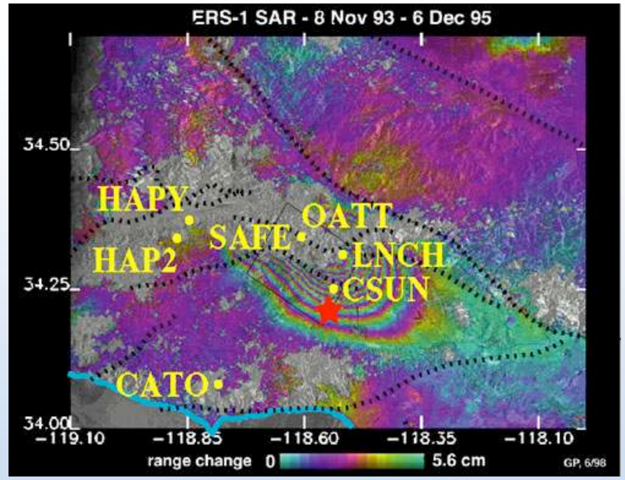
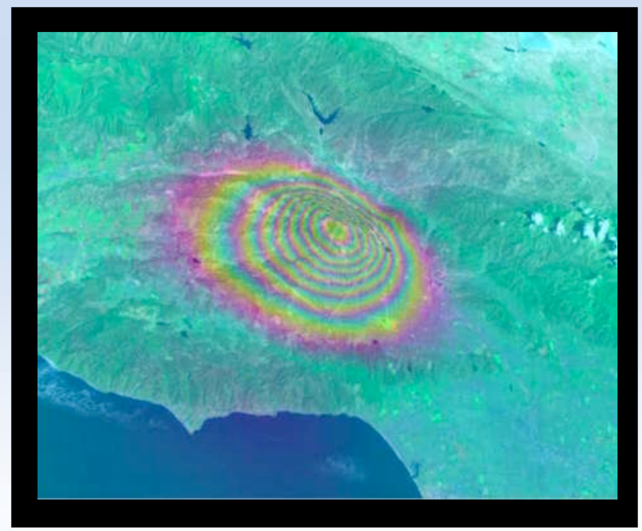
Visualizing the surface displacement data using RIVA

- GeoFEST – coseismic and postseismic vertical displacement on the Earth surface
- Virtual California – horizontal surface displacement caused by the simulated earthquakes
- The best way to visualize the surface displacement is synthetic interferograms.
- Interferogram shows the the surface displacement before and after an earthquake event in color fringes - a convenient way to compare the simulation results with the observation.

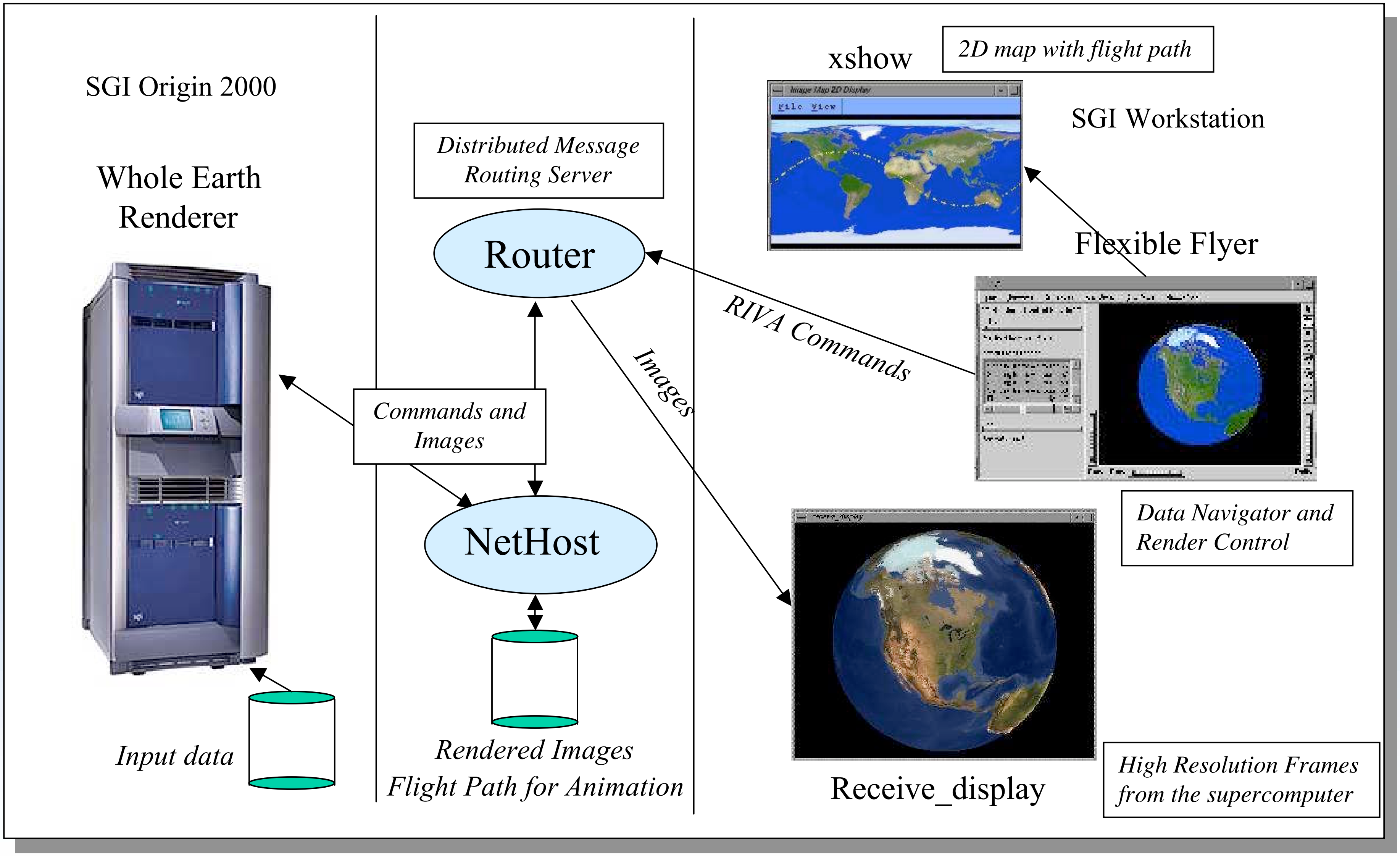


InSAR interferogram composited using two InSAR images taken before and after Northridge Earthquake

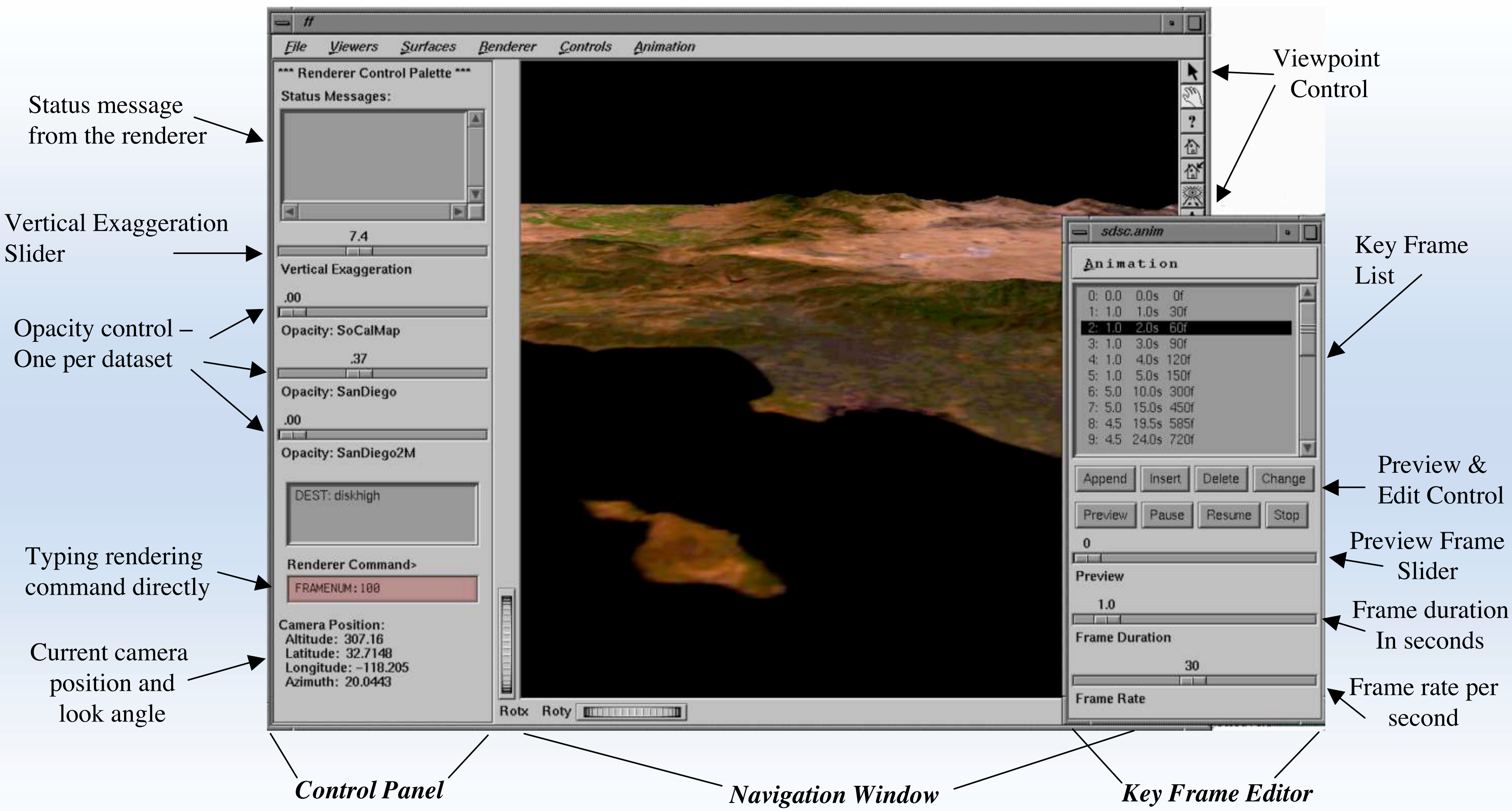


Synthetic Interferogram generated by the GeoFEST Northridge Model

RIVA System Architecture

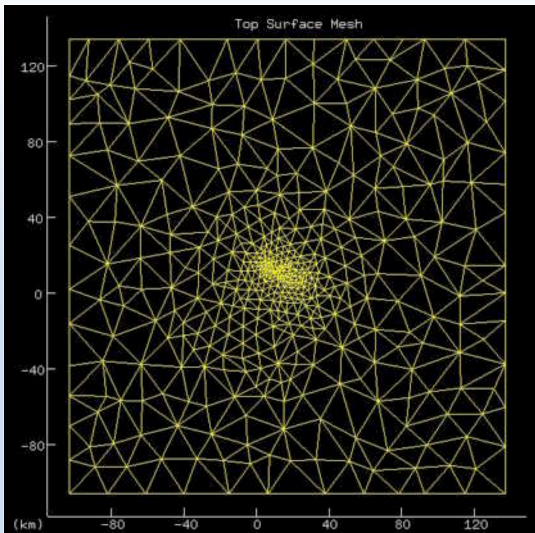


RIVA User Interface – Flexible Flyer

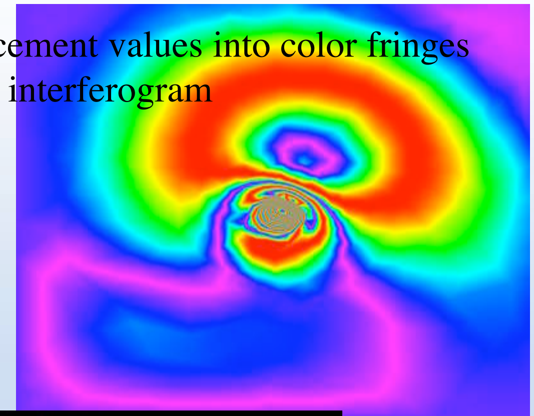


Visualizing GeoFEST surface displacement using RIVA

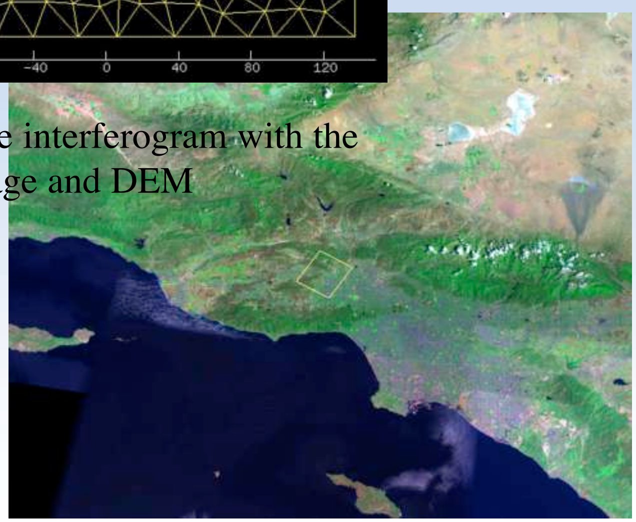
1. Extract surface displacement data from the 3D volume, calculate the accumulated vertical displacement after the earthquake.

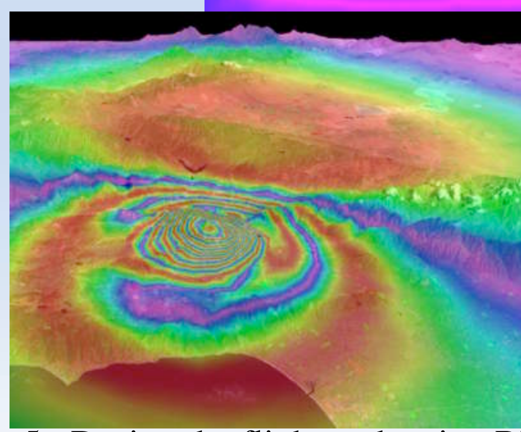


2. Interpolate the surface mesh into a lat-lon grid of a desired resolution
3. Convert the displacement values into color fringes to form a synthetic interferogram



4. Co-register the interferogram with the LandSAT image and DEM

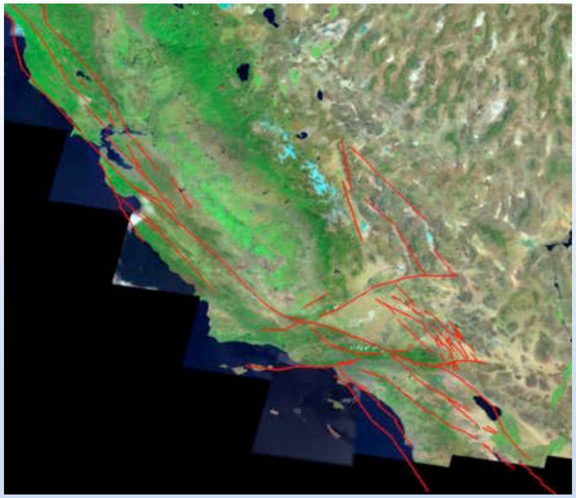




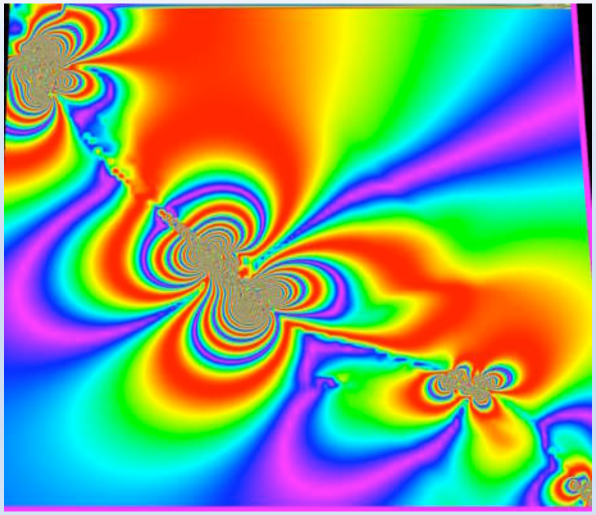
5. Design the flight path using RIVA key frame editor
6. Render the GeoFEST animation as a batch job.

Visualizing Virtual California surface displacement using RIVA

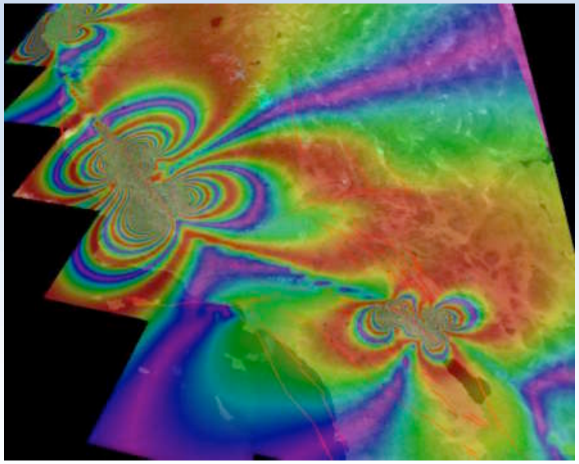
1. Map the VC fault table onto the LandSAT image



2. Interpolate the slips on the fault segments into a surface area.
3. Calculate the displacement difference for every 5-year moving windows, map the displacement into 5.6cm color fringe.

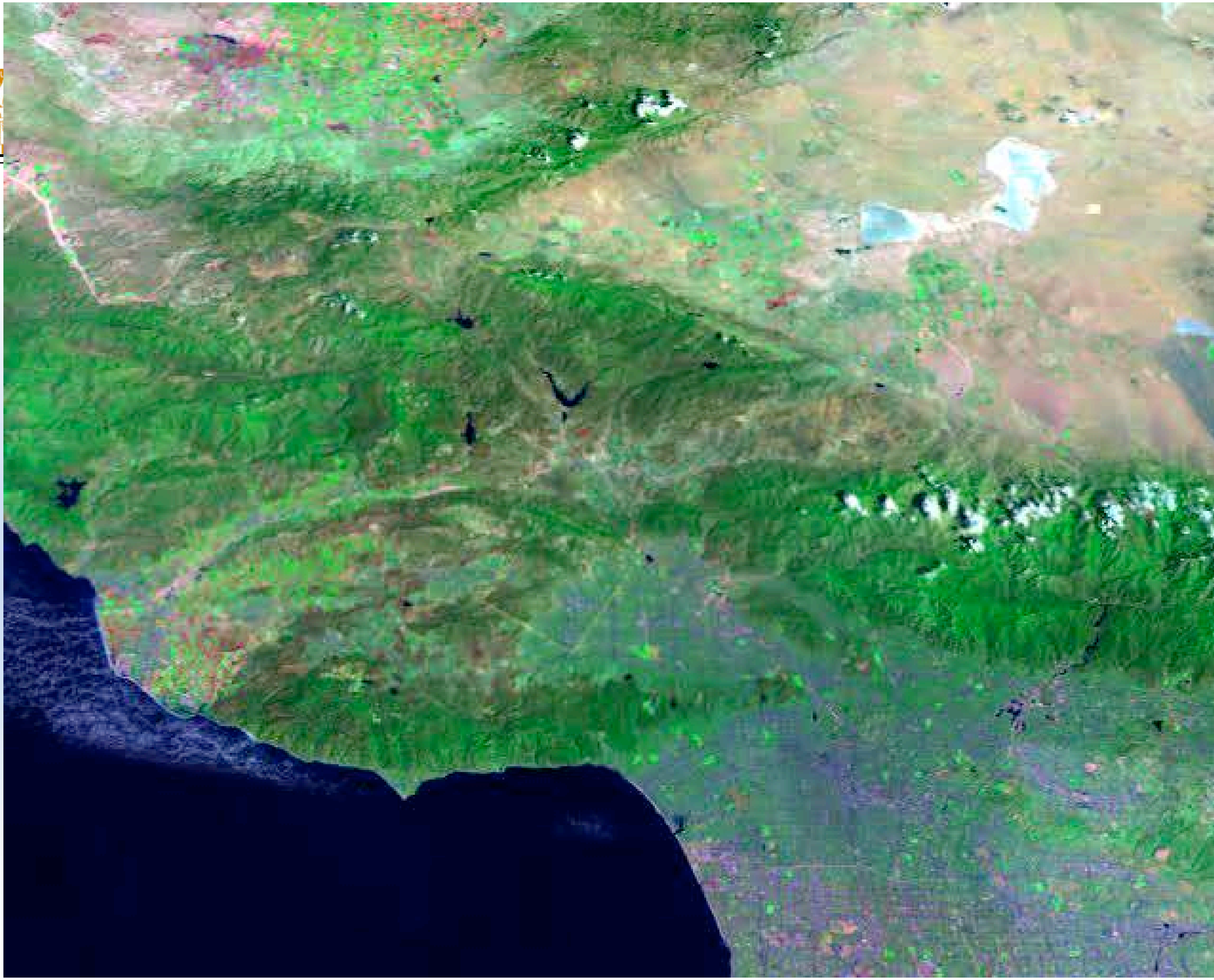


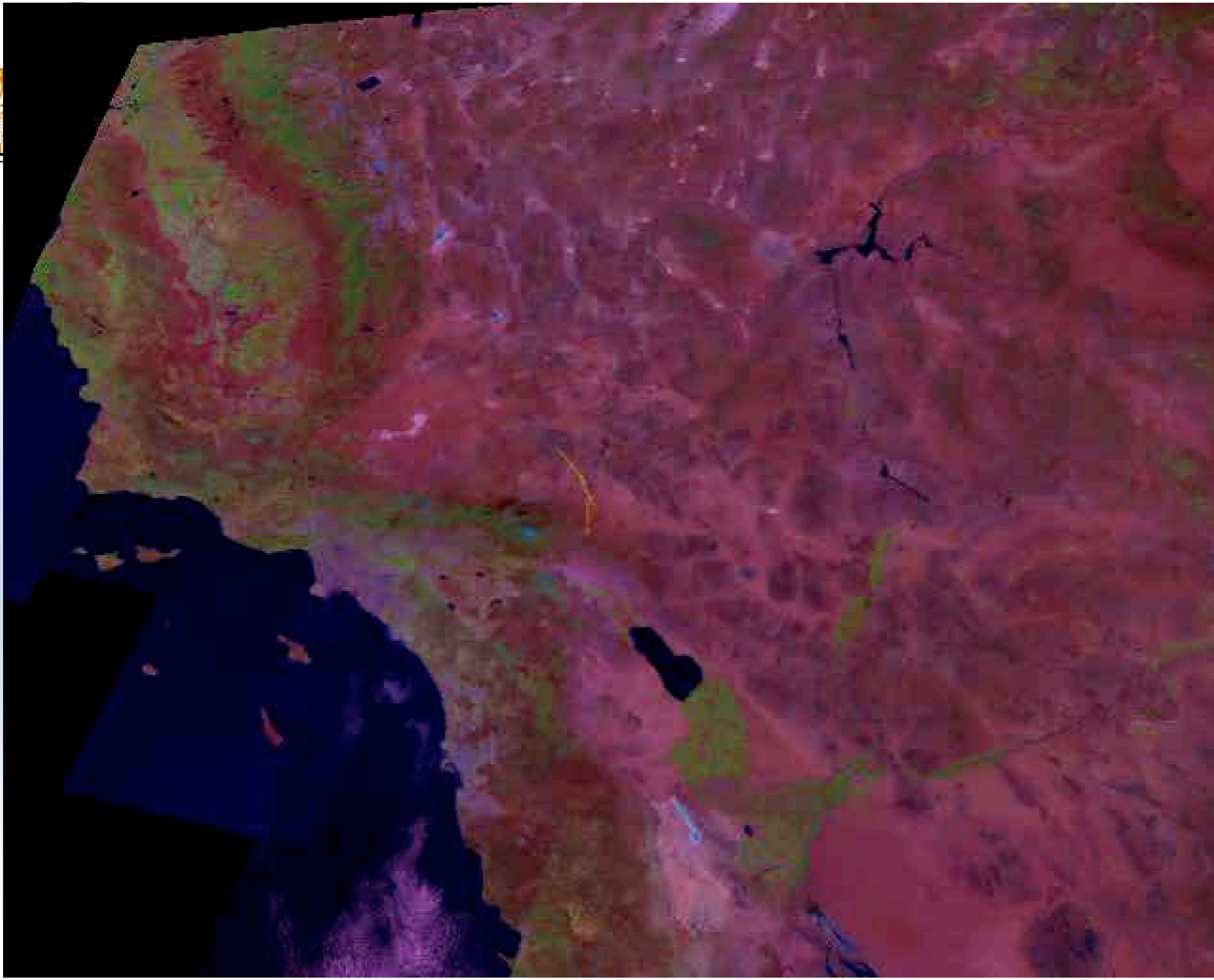
4. Co-register the interferogram with the LandSAT image and DEM

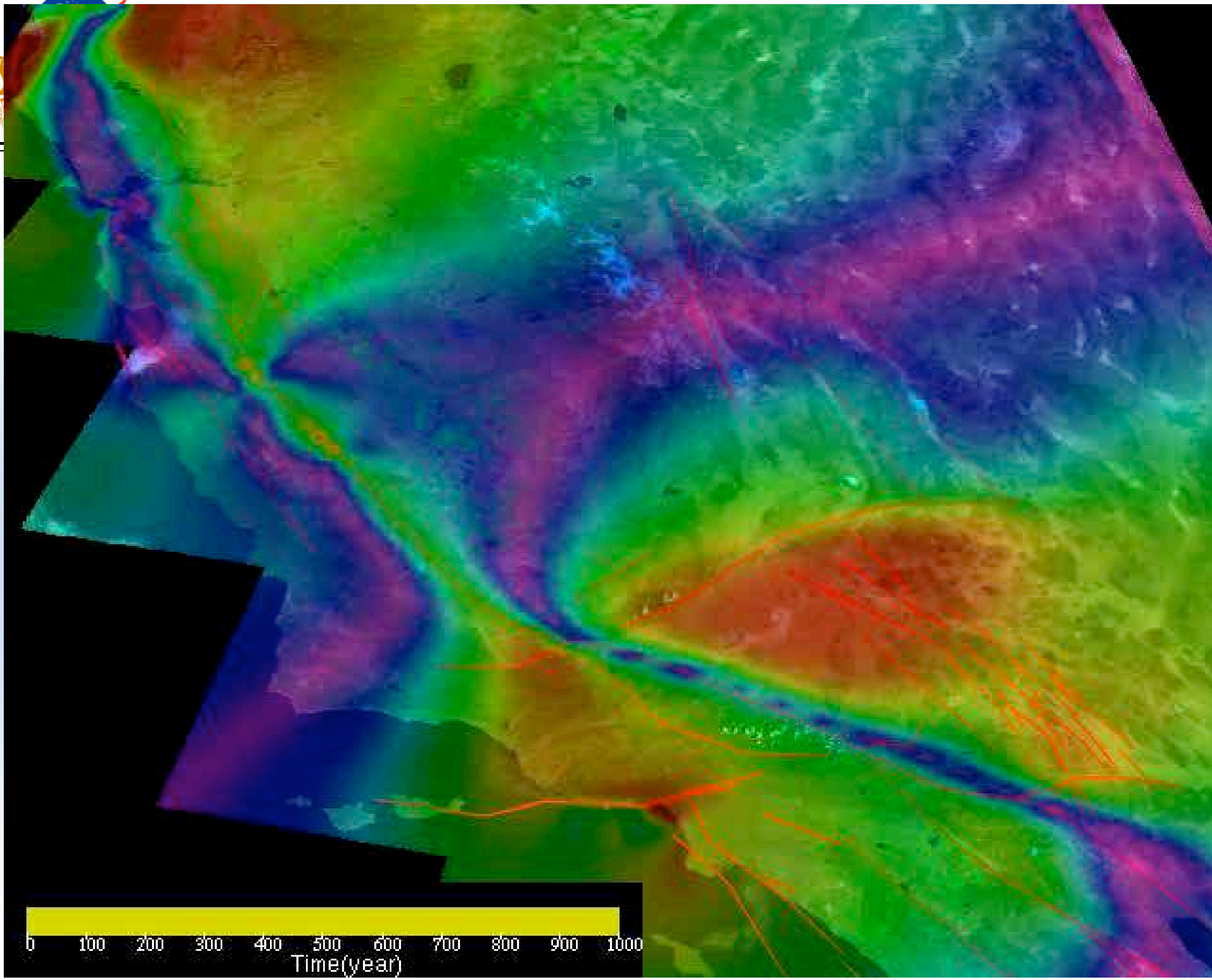


5. Design the flight path using RIVA key frame editor
6. Render the GeoFEST animation as a batch job.

- GeoFEST Northridge Model
- GeoFEST Landers Model
- Virtual California






0 100 200 300 400 500 600 700 800 900 1000
Time(year)

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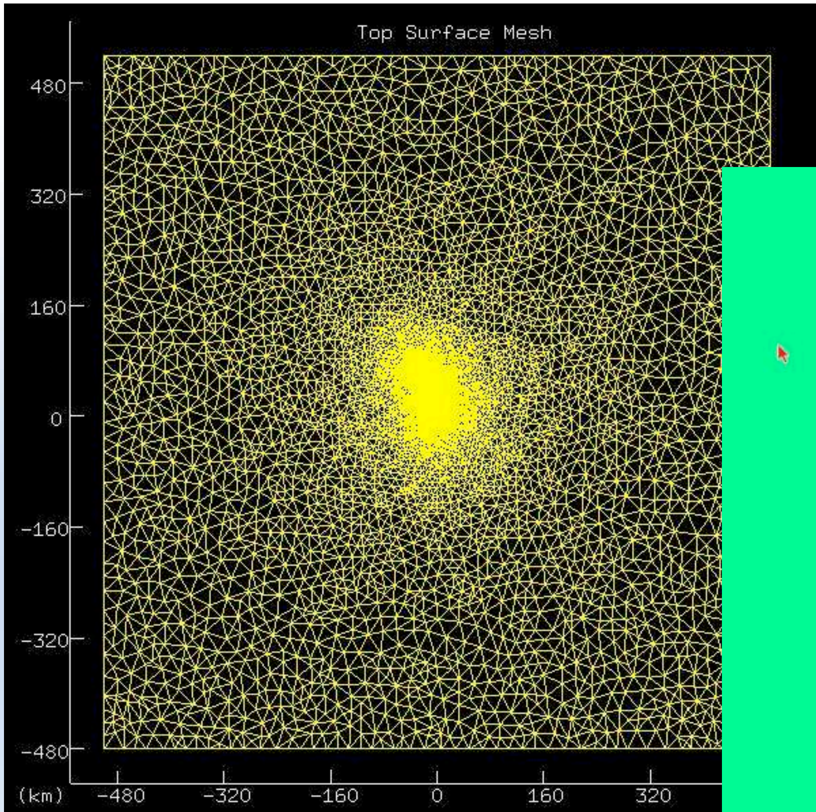
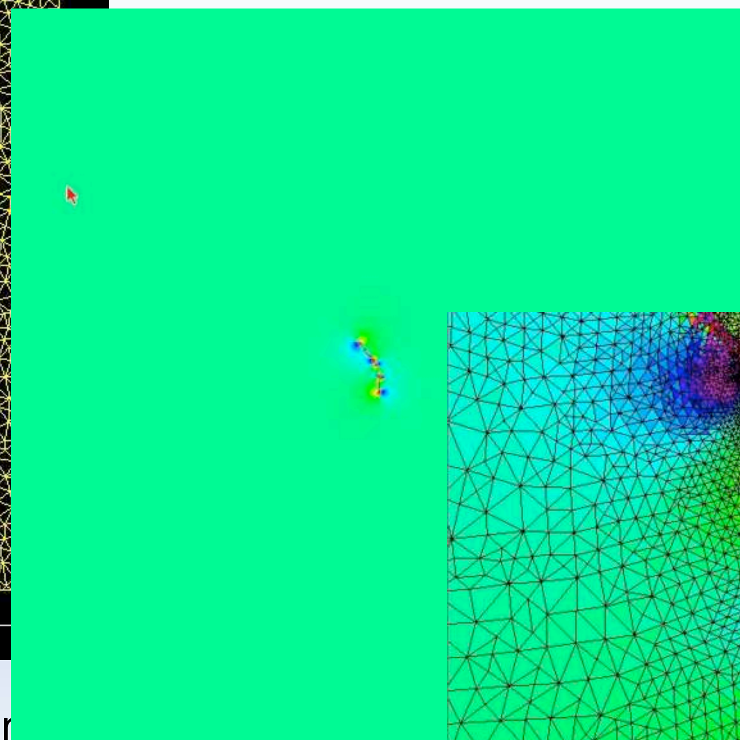
- GeoFEST produces stress tensors on the elements (the center of the tetrahedrons)
- Landers Model models three vertical faults that erupted during the earthquake.
- Landers Model contains 1.6 million elements that covers 1000km x 1000 km x 60 km volume with the densest meshes around the three faults.
- A typical simulation runs for 500 years with 0.5 year time step. The output data format is ASCII and the total output file size is 90 Gbytes.

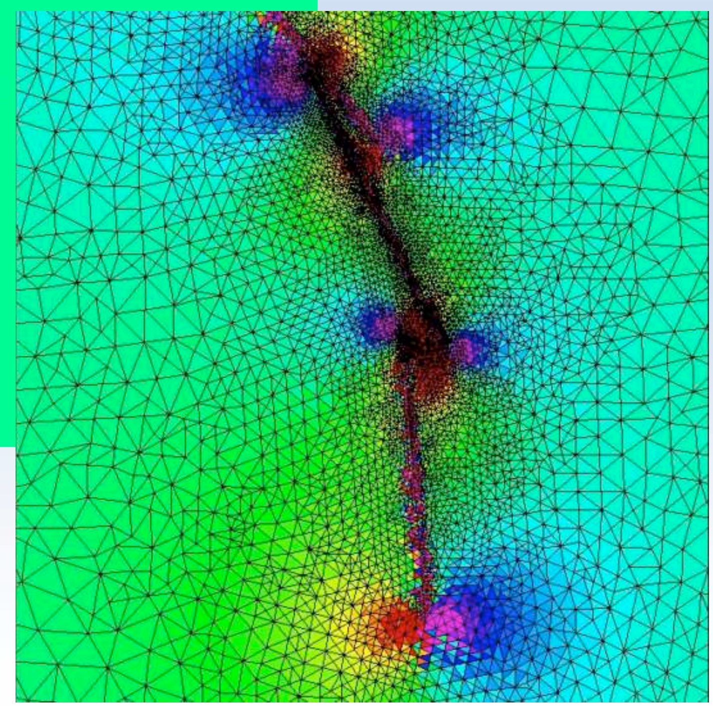
GeoFEST Landers Model



Surface mesh of Landers 1.6 million element model

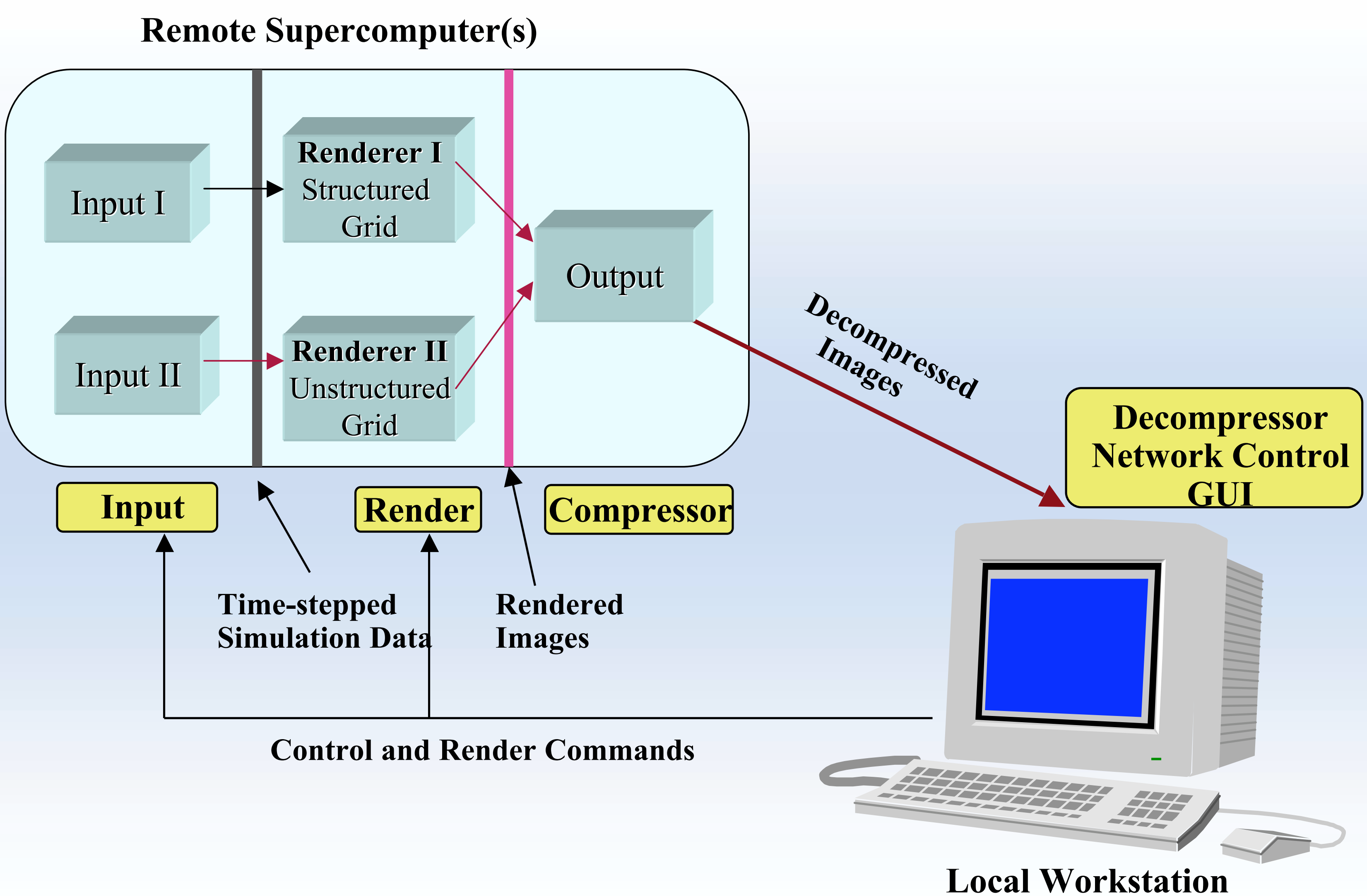
1st invariant of the stress tensor at the surface



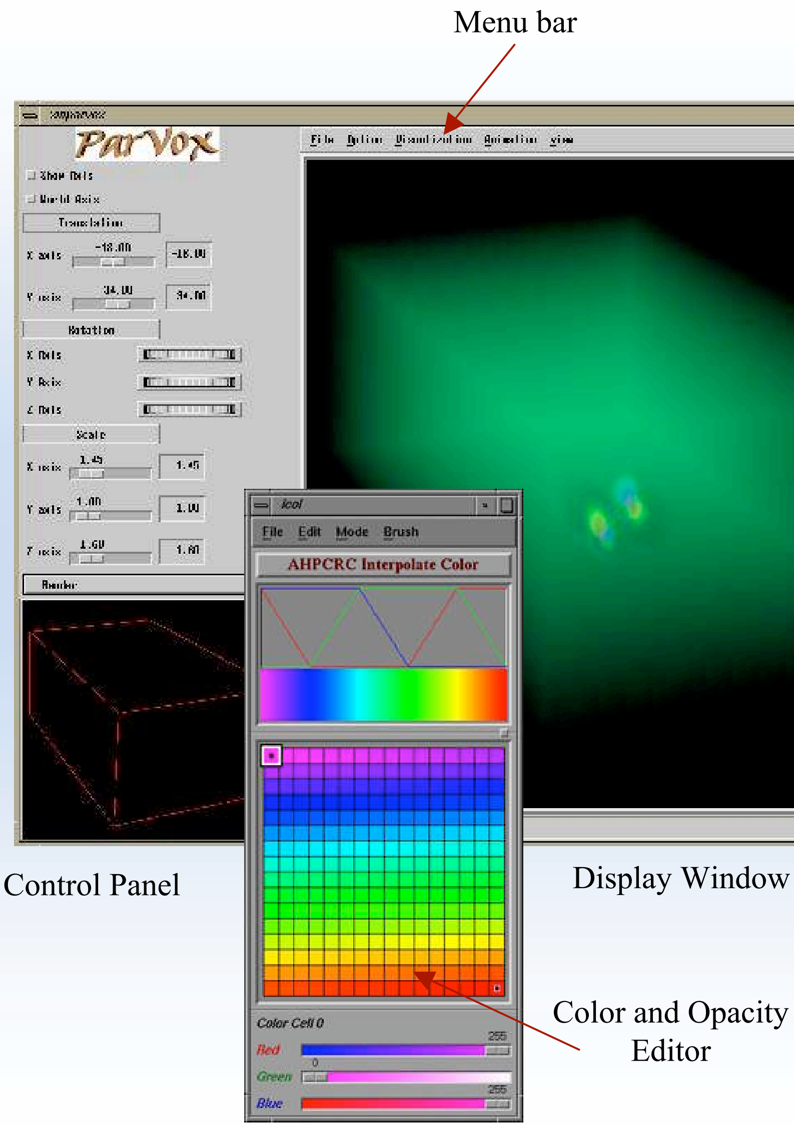


A closeup look of the mesh structure and the stress values

ParVox System Architecture

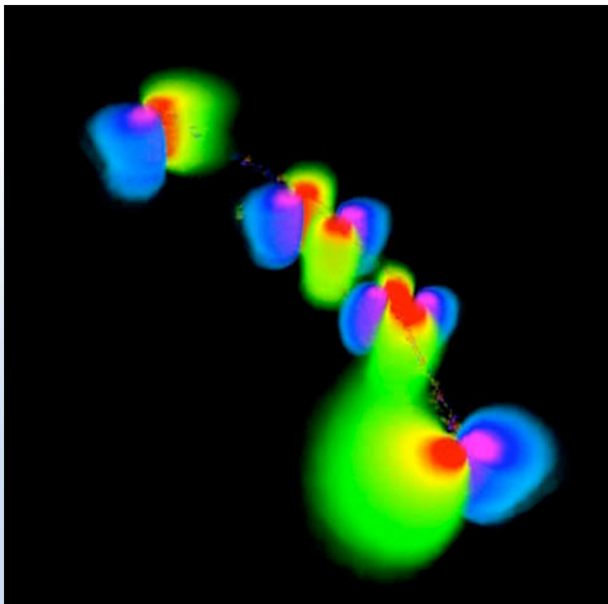


ParVox User Interface



- Visualization Challenge for GeoFEST dataset
  - Unstructured grid rendering: parallel cell projection
  - Perspective rendering
  - Viewing inside the volume
- Control Panels for
  - Viewing control
  - Volume control
- Color map and opacity map editing (*icol*)
- Animation control
- Save and restore rendering parameters

The Invariants of the Stress Tensor

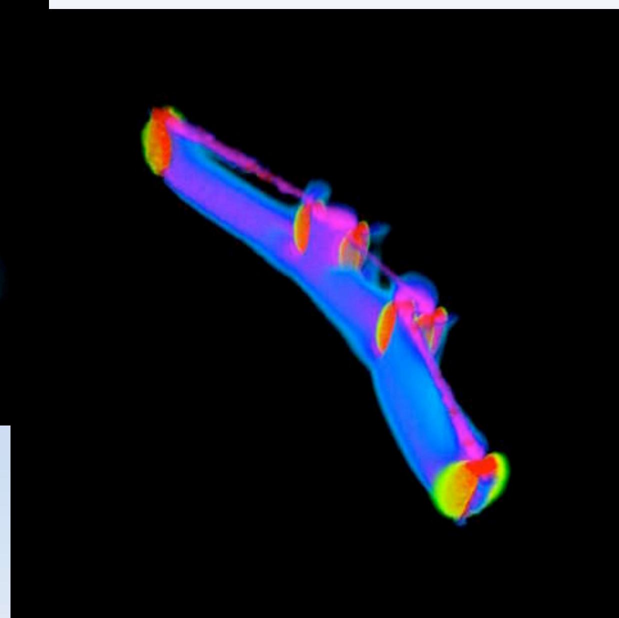


-10.0 10.0

I1= –xx+ –yy+ –zz

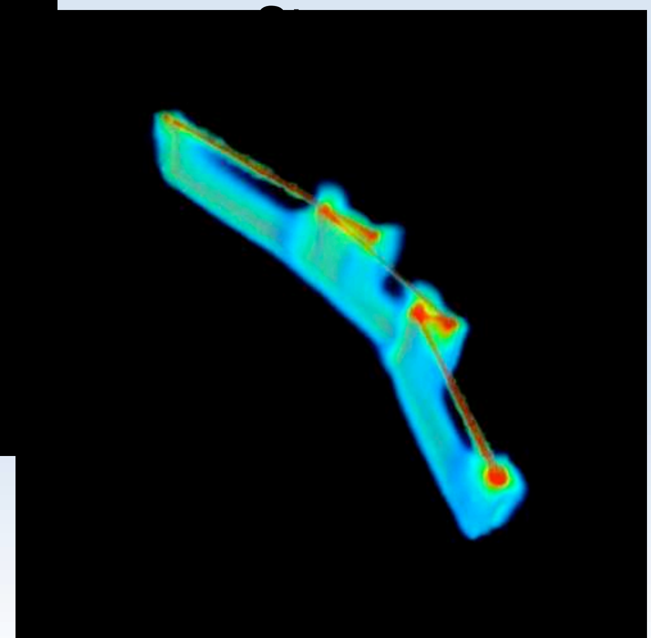
Volume Stress

I2= –xx –yy + –xx –zz + –yy –zz
– –²xy– –²xz– –²yz



-100.0 100.0

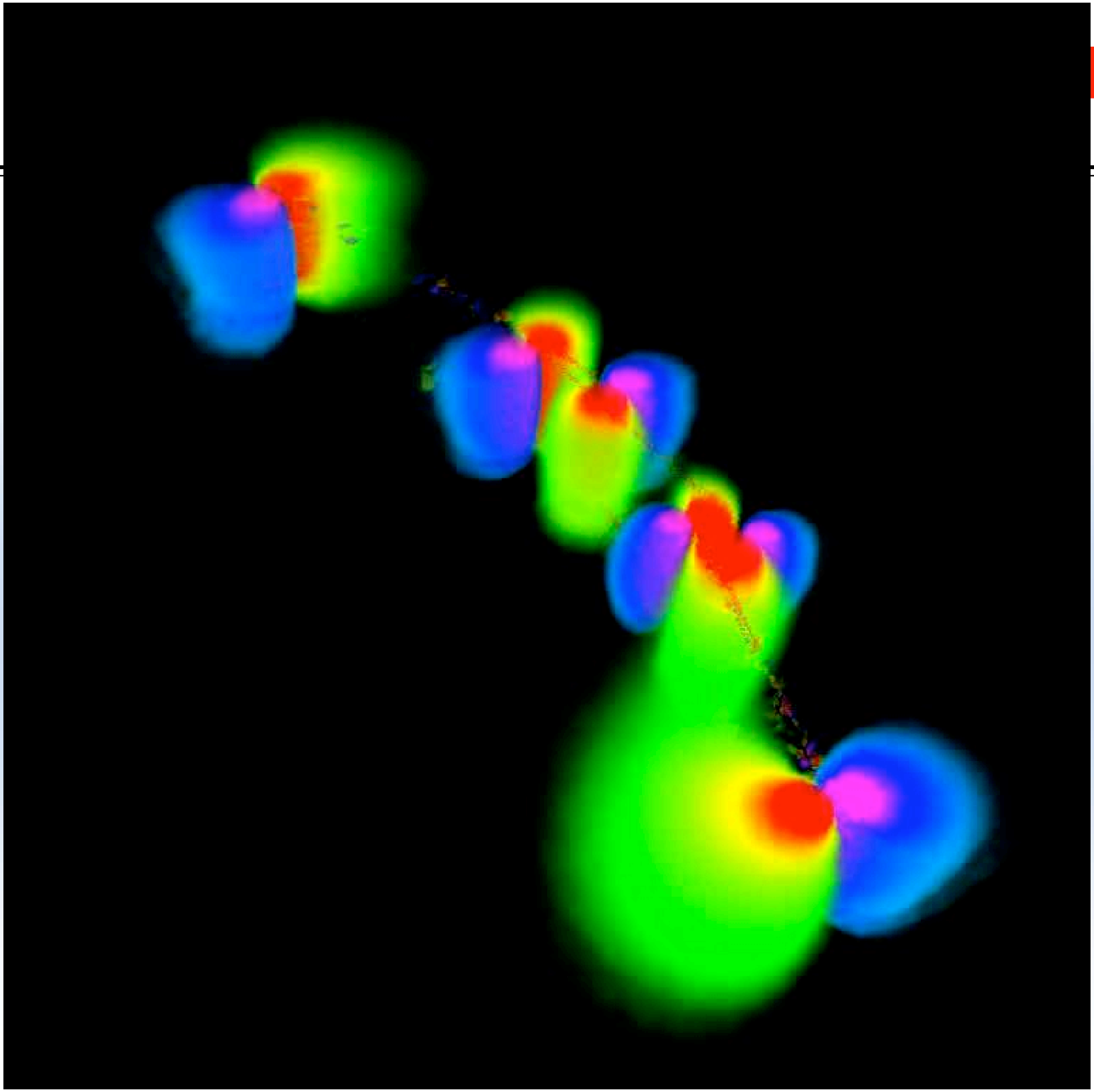
Shear



0 30.0

I3=0.0277–((–xx––yy)²+(–xx––zz)²+(–yy––zz)²
+ –²xy+ –²xz+ –²yz)

GeoFEST Landers Model



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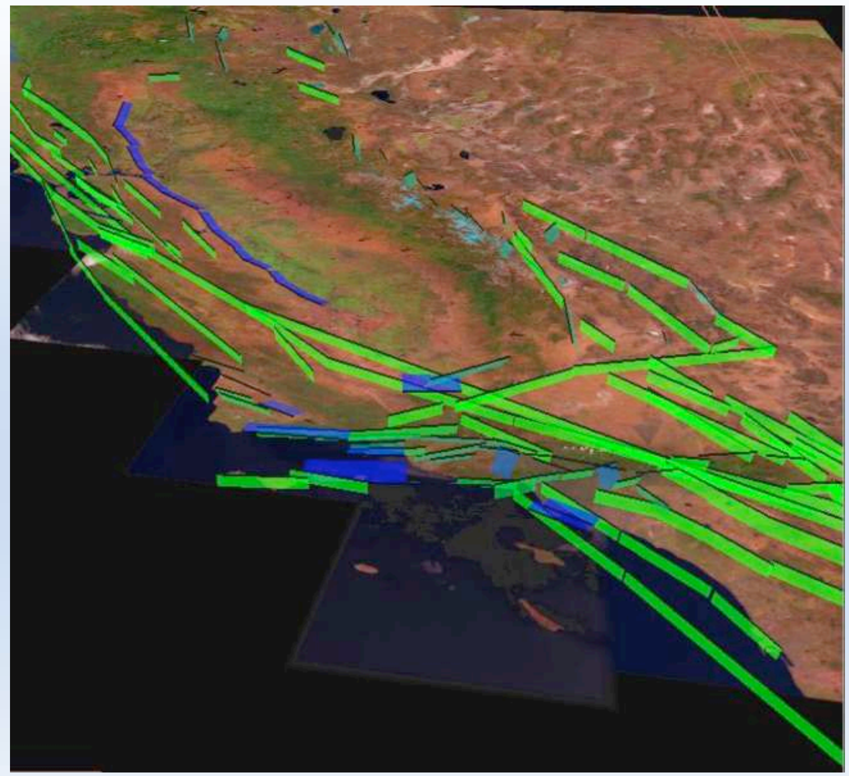
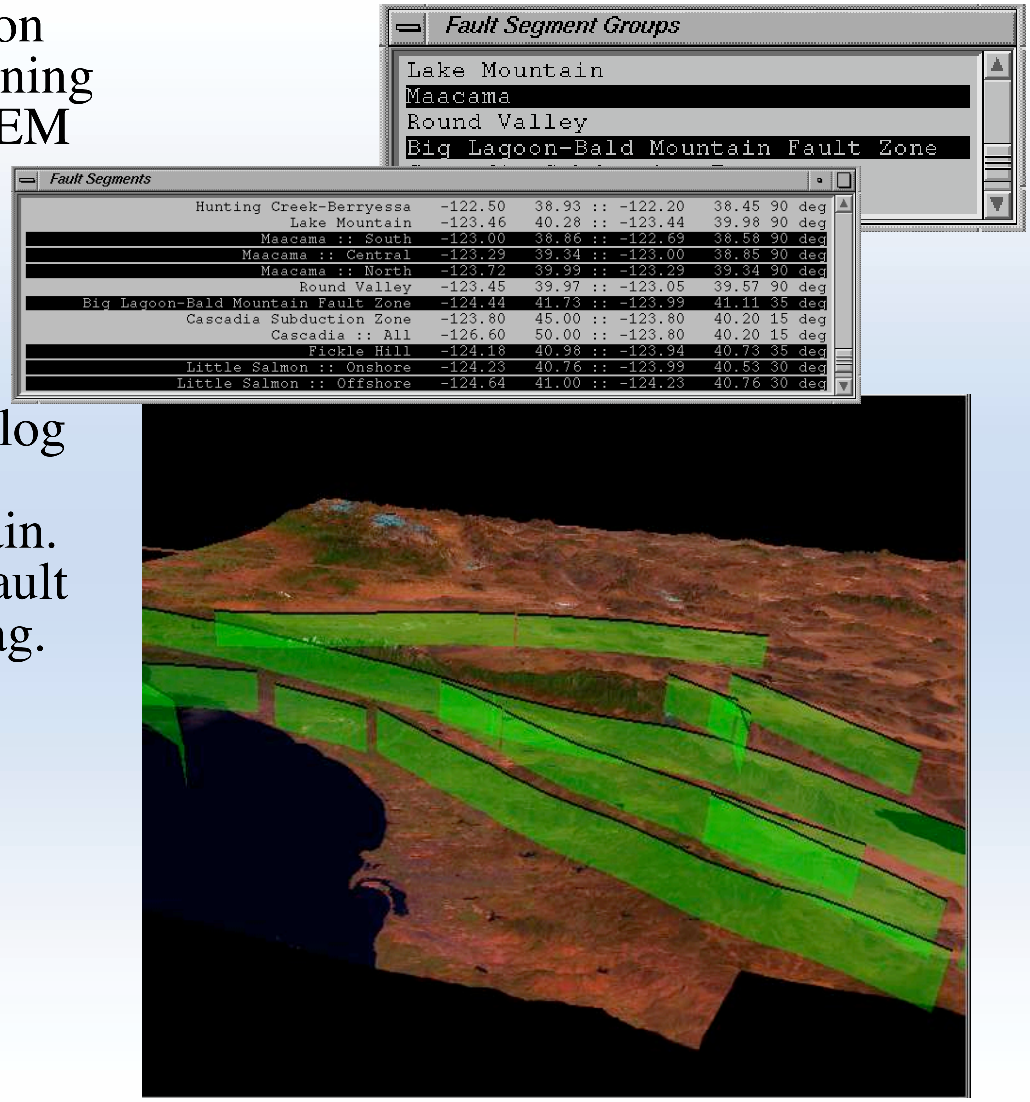
Fault Database

- QuakeSim project built an earthquake fault database based on pre-existing collections.
- The fault database is used for seismic hazard analysis and to drive simulations.
- The faults are divided into segments that are proposed to rupture as a unit. The fault parameters are from measurements and interpretations. The parameters include fault location, geometry, slip rate, rupture history and magnitude.
- The fault segments are best represented as rectangular surfaces underneath the terrain.



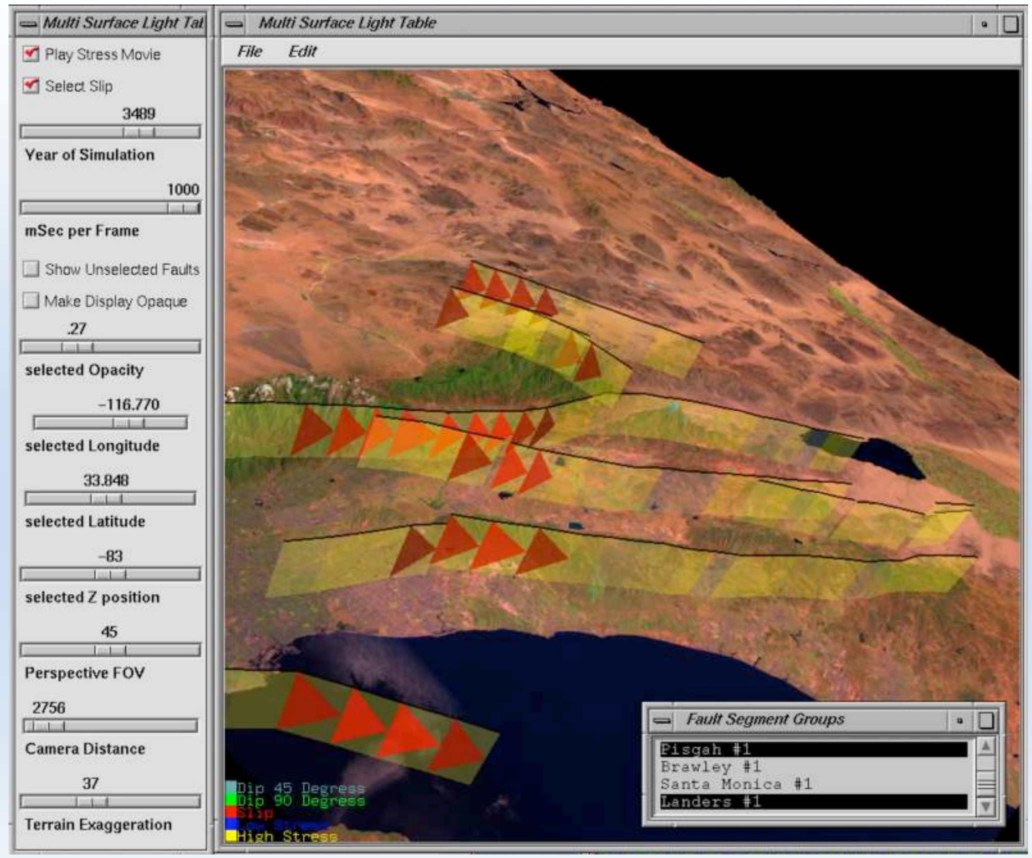
Multi-Surface Light Table (MSLT)

- Use hierarchical muiti-resolution data representation for fast panning and zooming of large image/DEM datasets.
- Display fault surfaces (as polygons) together with terrain image and DEM.
- View the fault database as catalog data as well as fault polygons overlaid on the image and terrain. Link the catalog data and the fault overlay by mouse click and drag.
- Use OpenGL and X Window, portable to Linux and all Unix platforms.



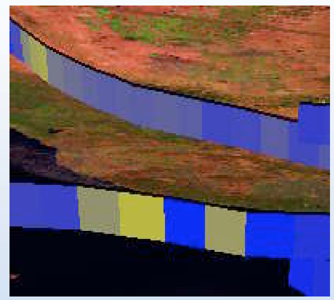
Viewing Simulated Slips and Stress on the fault segments

- Virtual California simulates the stress on the fault segments and slips caused by the simulated earthquakes.
- Virtual California fault database contains 60 strike-slip faults in California divided into 650 equal-length segments.
- Stress is displayed continuous in time and slip is displayed in discrete intervals.
- Stress is represented as color on the fault segments and slip as triangles.

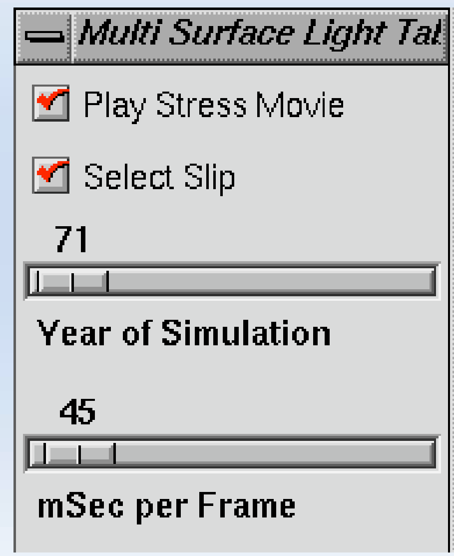


Represent stress as continuous colors

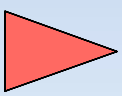
Low High



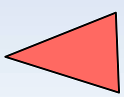
The animation speed and status are controlled at the control panel



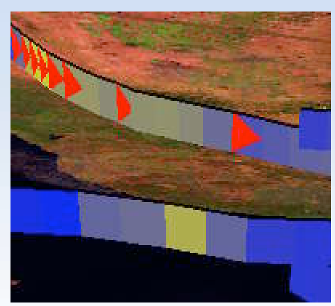
Represent slip a red triangles



Right Lateral Strike-Slip

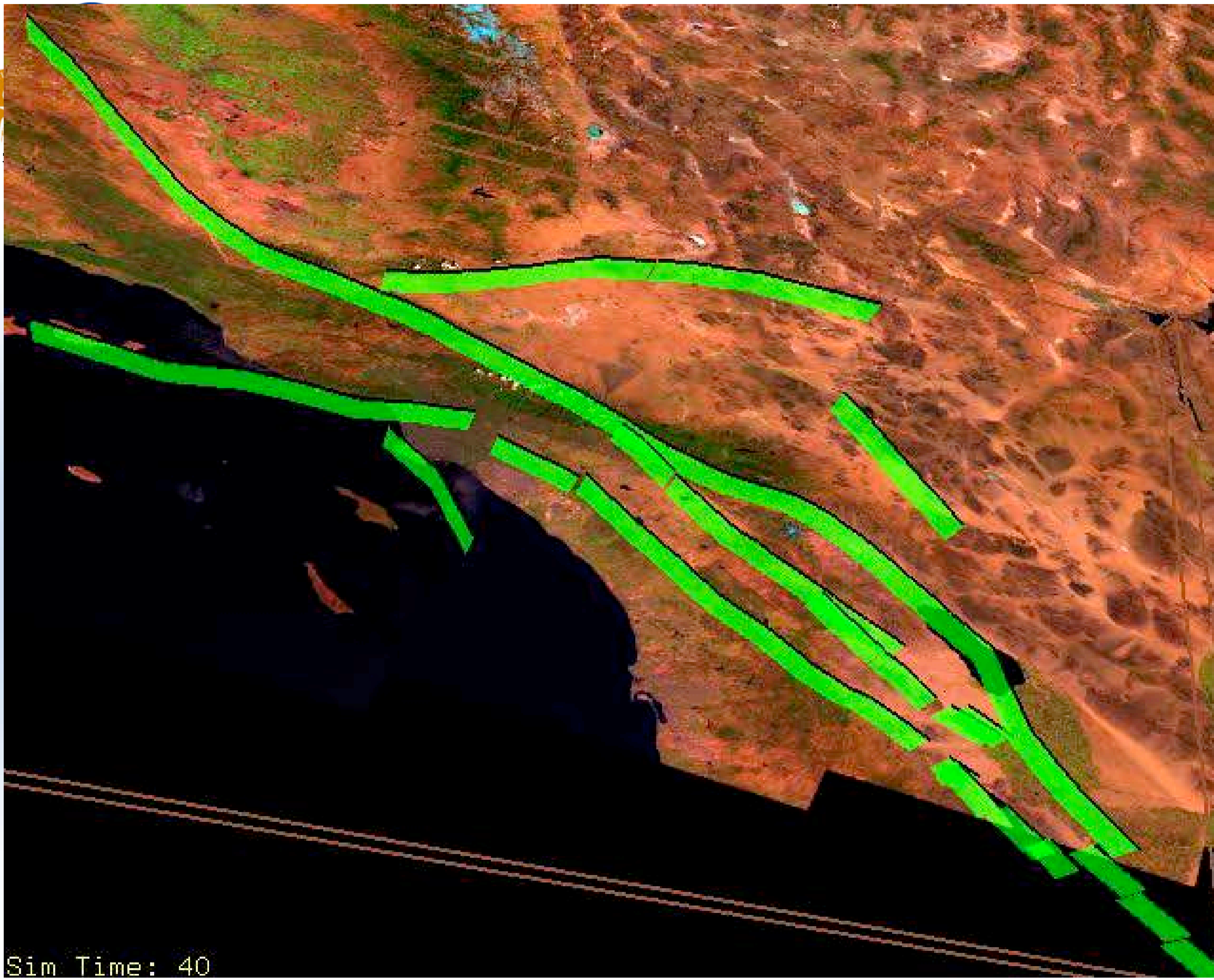


Left Lateral Strike-Slip



The duration and brightness of the triangles represent the magnitude of the slips

Virtual California Slip and Stress animation


Sim Time: 40

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- QuakeSim portal allows users to run the earthquake models on remote, distributed servers from a friendly web interface.

  1. To run GeoFEST with RIVA from the Portal
     - Select fault segments from the fault data base at USC
     - Define the model domain and run the mesh generator until a desired mesh resolution is achieved (at Indiana Univ.)
     - Run GeoFEST with user specified parameters (at Indiana Univ.)
     - Send the results to a visualization system (a SGI Origin 300 at JPL), interpolate the results into surface displacement interferogram, prepare the LandSat image and terrain, run RIVA with the simulation results using a predefined flight path and generate a mpeg animation.
     - Notify the user to retrieve the animation via the Portal when it is done.

2. To run GeoFEST with ParVox from the Portal
   - Select fault segments from the fault data base at USC
   - Define the model domain and run the mesh generator until a desired mesh resolution is achieved (at Indiana Univ.)
   - Send the mesh definition and GeoFEST configuration file to a parallel computer and run GeoFEST by submitting a batch job to its local queuing system. (a SGI Altix cluster at JPL)
   - Calculate the 1st and 2nd stress invariants and interpolate them from the elements to the nodes. Convert the data into ParVox NetCDF format. Start interactive ParVox session.
   - Notify the user to start the ParVox GUI program on his/her workstation to view the GeoFEST Stress Volume interactively.

Status and Conclusion

- The task started in February 2002 and will complete in September 2004.
- Developed support for time-sequence simulation data for RIVA.
- RIVA 1.0 source code was released to public via OpenChannel in 8/2003.
- Developed support for perspective rendering of unstructured grid volume and viewpoints inside the volume in ParVox.
- ParVox 2.0 will be released to public via OpenChannel at 9/2004.
- RIVA and ParVox have been integrated into the QuakeSim portal as visualization tools for GeoFEST.
- Developed MSLT software on Unix and Linux stations.
- MSLT 1.0 will be released to public via OpenChannel as soon as the export license is approved.
- A web-enabled MSLT prototype will be developed by 9/2004.

Acknowledgements

- ParVox, RIVA and MSLT development was sponsored by ESTO-CT Office with Jim Fischer and Robert Ferraro as managers.
- QuakeSim team is lead by Dr. Andrea Donnellan, managed by Michelle Judd of JPL.
- Dr. Jay Parker, Dr. Greg Lyzanga and Dr. Charles Norton of JPL provided GeoFEST Northridge and Landers model data output and made numerous suggestions on how to visualize the data effectively.
- Dr. John Rundle of UC Davis provided the Virtual California software and datasets. He also provided valuable suggestions on the presentation of the data in MSLT and RIVA.
- Dr. Marlon Pierce of U. Indiana developed the web services to integrate RIVA and ParVox into the QuakeSim portal.
- Dr. Marlon Pierce and Ann Chen of USC developed the Java client to access the QuakeSim fault database.
- Access to the JPL supercomputing facilities, including SGI Origin 2000 and SGI Altix, was made possible by JPL Supercomputing Project and JPL Supercomputer and High Definition Systems Group.